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Review

Animal welfare at markets and during transport and slaughter

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ABSTRACT

This review highlights some recent developments in our understanding of stress and physical injuries that occur before and during transport to slaughter, during handling at livestock markets, and at the time animals are put-up for slaughter within abattoirs. Stress in pigs during transfer to the stunning point within the abattoir has important effects on meat quality, and there is growing evidence that strenuous exercise or CO_2 stunning can contribute to oxidative rancidity in pigs, poultry and fish. In the EU, putting cattle through a crush in order to check that their eartag numbers correspond to their passport numbers is imposing additional stress, and there are reports that it is leading to greater hide contamination with *Escherichia coli* O157. Recent developments in stunning and slaughter include a better understanding of the causes of variation in captive bolt gun performance, the effectiveness of poll instead of frontal shooting in water buffalo, the prevalence of false aneurysms in carotid arteries during shechita and halal slaughter, and the stress effects of CO_2 stunning in fish. Stunning pigs with 90% CO_2 leads to less PSE meat than 80% CO_2. There have been concerns about the physical activity that cattle show following electrical stunning with an electrically induced cardiac arrest, and with electrical stunning using DC waveforms in broiler chickens. There is also growing concern about the hygiene problems that exist in wet markets, where animals are slaughtered alongside meat that is on display to customers.

Contents

1. Introduction

This paper summarises some key findings from recent research into animal welfare during the preslaughter and slaughter periods. It focuses on injuries and ease of handling, stress effects on subsequent meat quality, and contemporary problems in stunning and slaughter.

2. Recent trends in preslaughter management

Certain breeds, such as Limousin, Red Bororo cattle and Texel sheep, are difficult to handle (Minka & Ayo, 2007; Tompsett &

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Gregory, 2008). It is often recommended that such animals should be familiarised with handling procedures, as this makes them easier to manage during the preslaughter period. There is no doubt that familiarisation helps, but in the case of pigs, a potential disadvantage is that familiarised animals have higher counts of enteric bacteria per gram of faeces in their excreta during the presalughter period (Dowd, Callaway, & Morrow-Tesch, 2007). The mechanisms that explain these and other stress-related effects on enteric bacteria and virus populations are not understood, and they need investigating.

It is also widely recognised that preslaughter stress starts as animals are being loaded onto the vehicles that take them to abattoirs. However, there are two recent studies showing that it can start earlier than this. Under Australian conditions, pre-transport stress or underfeeding were present in five out of 13 lamb consignments as determined from depletion of muscle glycogen in biopsies taken before loading (Jacob, Pethick, & Chapman, 2005). Previous work by the same group showed there was a linear correlation between muscle glycogen concentration and ME intake, and so it was suggested that improvement in nutritional management should solve a good part of this problem. However, there were four lamb consignments with lower muscle glycogen concentrations on arrival at the abattoir compared with levels before leaving the farm, and three of those had been fed grain before embarkation.

The second study was in New Zealand. When New Zealand lambs are prepared for slaughter they are usually graded and crutched shortly before leaving the farms. When this was done, along with weighing, it was found that it took the lambs more than 3 days to recover a normal pH_{ult} in the *longissimus dorsi* (Devine et al., 2006). The intermediate pH_{ult} meat (5.75–6.00) in lambs given insufficient time to recover resulted in tougher meat, but the toughness disappeared if the meat was allowed to age.

There are mixed reports about whether handling stress in the abattoir before slaughter is being adequately controlled. In the EU the situation started to deteriorate with the introduction of cattle passports ten years ago. Introducing cattle passports increased the amount of preslaughter handling. Cattle must have their ear tag numbers checked against the number in the passport each time they are sold at markets and when they are presented for slaughter at an abattoir. This involves holding them in a crush, and as with any crush-work, some animals get bruised and others react badly to being confined. In addition, in a study on cattle sent from 30 farms to 10 abattoirs in Scotland, putting cattle through a crush in the lairage was found to increase hide contamination with *E. coli* O157 (Mather et al., 2007). By contrast, the situation in the USA where passports are not used is improving, in terms of the prevalence of vocalising, thanks to closer attention to welfare auditing (Grandin, 2006; Table 1).

When animals are forced to take strenuous exercise, muscle is prone to forming lipid peroxidation metabolites. The mechanisms that explain this are understood, but there have been few situations where it has been found to affect meat quality (Gregory, 1998, 2007). Ten minutes preslaughter exercise on a treadmill (3.8 km/h) resulted in slightly higher TBARS development in heated pork meatballs, compared to product from unexercised controls, but this must have been quite a severe stress compared with usual practice (Young et al., 2003). Preslaughter heat stress and CO_2 stunning could be more common factors leading to oxidative rancidity (Mujahid, Akiba, Warden, & Toyomizu, 2007). TBARS concentration in broiler breast meat was higher in CO_2 stunned than electrically stunned birds (Alvarado, Richards, O'Keefe, & Wang, 2007). TBARS formation was particularly pronounced in poorly bled birds (Table 2). CO_2 stunning in trout also leads to greater TBARS formation compared to killing by holding in ice (Giuffrida et al., 2007). Whether this was due to their greater exercise or to the potency of carbonate radicals as membrane lipid oxidising agents is not clear.

The way in which pigs are reared can affect ease of handling during the preslaughter period and the extent to which they have to be encouraged to get them to move. Pigs reared on slatted floors were more difficult to load onto vehicles, showing more balking, compared with pigs reared on solid floors. This could have been due to the novelty of the floor type, and because they seem to be more reluctant to move generally (Nanni Costa, Tassone, Righetti, Melotti, & Comellini, 2007). They were, however, less likely to slip during loading.

Hambrecht et al. (2005) compared the relative effects of transport stress, lairage duration and rough handling during transfer in the lairage to the stunning point on subsequent meat quality in stress resistant pigs under European conditions. Stressful handling during transfer to the stunner had the biggest effect on pH_{ult} and on muscle lactate concentration at 2–3 h post-mortem. This was not surprising in the case of muscle lactate, but the 0.13 unit increase in pH_{ult} from mishandling immediately before slaughter was unexpected. The general conclusion was that the greatest benefits in terms of meat quality are likely to come from reducing stress in the lairage during the final stages before slaughter.

The importance of exercise and handling stress immediately before stunning could be even greater in hotter climates. The remedy, however, is not always straight-forward. It is recognised that under subtropical conditions, antemortem showering helps to relieve heat stress in pigs, and this should help alleviate the immediate preslaughter acidosis that contributes to PSE meat. In broilers, however, there is a risk that showering birds can lead to a higher proportion of high pH_{ult} meat, especially when it is applied too enthusiastically (Guarnieri et al., 2004).

One of the ugliest aspects of preslaughter handling is the way downer animals are managed at abattoirs. These are animals that are either injured, or are too weak, or too sick to stand and walk. In the US, in 1994 and 1999, 1.15% and 0.8% of cattle waiting in pens at abattoirs were culled because they were in this condition. This amounted to 71,117 and 49,520 cattle, of which 1.1% and 1.5% were dairy cows and 0.7% and 1.1% were beef cattle (Stull, Payne, Berry, & Reynolds, 2007).

Table 1
Change in prevalence of repeat shooting and vocalising in cattle in US abattoirs in recent years

	1996	1999	2003
Number of abattoirs	6	41	50
Cattle vocalising during handling + stunning (%)	8	2.4	2.0
Range	1–32	0–17	0–6
Number of abattoirs	10	41	50
Cattle stunned with first shot (%)	89.5	96.2	98.6
Range	80–95	84–100	92–100

Table 2
Effect of different stunning methods on muscle haem pigment concentration and TBARS formation in breast meat cooked 4 d after slaughter

Stunning and slaughter method	Meat TBARS	Muscle haem
	mg/kg	μmol/g ± SE
CO_2 stunning – not bled	11.13[a]	10.04 ± 1.70[a]
No stunning – bled	10.72[a]	8.37 ± 1.80[b]
CO_2 stunning – bled	10.56[a]	8.53 ± 1.38[b]
Electrical stunning – decapitated	9.63[b]	8.40 ± 1.72[b]
Electrical stunning – unilateral cut	8.75[c]	8.72 ± 1.66[b]

Means in a column with a different superscript letter were significantly different at least at $p = 0.05$.

Table 3
Injuries in cattle and water buffalo presented at a market in Bangladesh

	Cattle	Water buffalo
Number of animals examined	368	192
Animals imported from India (%)	78	Not known
Nose piercing		
Nose pierced (%)	69	54
Animals suppurating at nose (%)	46	40
Tail injuries		
Kinked tail (%)	51	15
Tail end absent (%)	1	1
Skin injuries		
With skin injuries (%)	84	99

We do not have a more recent estimate of the prevalence of this problem.

3. Transport

International cattle transport has attracted interest on two fronts in recent years. The first has been cattle shipped from Australia for slaughter in the Middle East (Sidhom, 2003). The handling at Cairo abattoir has drawn poor publicity, along with the ways Australian sheep have been managed in Oman. The second area of concern has been with water buffalo and Hariana cattle exported from north India for slaughter in Bangladesh. India has more cattle than any other country and yet, for religious reasons, it does not have a correspondingly high cattle slaughter rate. There are very few recognised beef abattoirs in India, and export agents are thinking of diverting cattle away from Bangladesh to more lucrative markets in the Middle East. There are moves to improve the welfare image of the export trade in Bangladesh to help sustain this important source of dietary protein. The animal welfare problems include ulceration and bleeding where ropes are secured in the noses, broken tails, and skin lacerations and grazing (Table 3). Many of the injuries were recent injuries and were probably due to contact with the inner walls of the vehicles during transport (Table 4). Some could be corrected through better awareness amongst the stock handlers (Alam, in preparation).

Injuries are also common in Nigerian cattle, and it is estimated that 34% of the injuries are due to horns. Red Bororo cattle are difficult to load onto livestock trailers compared to white Fulani or Sogoto Gudale and they are more prone to injuries. The Red Bororo breed is generally more difficult to handle and this was reflected in the time it took to get them loaded. Red Bororo had more fractures (3%), dislocations (3%), lacerations (20%) and muscle bruising (43%) compared to Sogoto Gudale (2%, 2%, 8%, 23% respectively), which is a placid draught breed (Minka & Ayo, 2007). It is likely that Red Bororo also incurred injuries because of their loose thin skin and long horns. Overall, the prevalence of cattle without any injuries by the end of 10–12 h journeys was 21%, and the prevalence with injuries doubled during the last 6–8 h of the journeys. It is common for journeys to take 2–3 days to reach the slaughter destination. Temperatures inside the livestock trailer during the hot-dry season vary between 22 and 33 °C, and can rise to 35 °C when the vehicle stops. Under these conditions, weight loss would be expected during journeys lasting more than a day.

Under central European conditions, 42-day old broilers lose 7 g more weight per bird when transported 1.5 h at a high stocking density (0.0350 m^2/broiler) compared to a lower density (0.0575 m^2/broiler) (Delezie, Swennen, Buyse, & Decuypere, 2007). The higher density would be typical for present standards, and the saving in weight loss from using the lower density would be equivalent to one bird per module. For a plant processing 200 modules a day this would be equivalent to a saving of 200 birds, which could make the lower density financially attractive.

In recent years in the UK, cattle farmers have been using their own vehicles to transport animals instead of hiring professional hauliers. This has cost-saving advantages, provides farmers with more flexibility in deciding when to sell and it gives some farmers an opportunity to hire out vehicles when they are not in use. There may be a food safety advantage as well. Transporting cattle to an abattoir by a haulier is more likely to be associated with contamination of the hide with *E. coli* O157 compared with transport by the farmer (Mather et al., 2007).

Table 4
Prevalence of skin injuries in 560 cattle and water buffalo presented at a market in Bangladesh

Types of injuries	No. of affected animals	Percentage (%)
Abrasion	410	73.2
Laceration	229	40.9
Penetration	21	3.8
Ulceration	7	1.3
Bleeding	16	2.9
Swelling	47	8.4
Hyperkeratosis	104	18.6
Scar	279	49.8

(Alam, in preparation).

4. Welfare at livestock markets

In Europe, selling livestock through auction markets (saleyards or salebarns) is losing favour with retailers and governments. This stems from four concerns. Firstly, it has been difficult to trace meat back to the farm of origin when animals have been sold through livestock markets. The worry is that when there is a food safety alert, such as BSE, it will be difficult to identify the source of the problem. That concern is no longer valid in those countries that have introduced cattle passports, as passports now allow an adequate level of traceability. Instead, this concern has been replaced by worries about transmission of disease within markets. This is supported by science-based risk analysis, and it applies particularly to contagious exotic diseases (Bigras-Poulin, Thompson, Chriel, Mortensen, & Greiner, 2006; Robinson & Christley, 2007; Schembri, Hart, Petersen, & Whittington, 2006). In Africa, however, transhumance is probably a greater disease risk than submitting stock for sale in markets (Bonsvoort et al., 2004). The third concern about livestock markets is the effect it has on animal cleanliness. Putting cattle through markets can increase the risk of hide contamination with undesirable bacteria (Collis et al., 2004). The fourth concern is that the welfare of animals sold through markets is poor compared with animals delivered directly to abattoirs (Murray, Davies, Cullinane, Eddison, & Kirk, 2000).

The welfare concerns with putting fat cattle through markets include fatigue, fear and distress, fasting, dehydration and injuries. It is well recognised that the prevalence of carcass bruising in cattle sold through markets is higher than for cattle sold direct to abattoirs, and this is cited as evidence that auction marketing is less appropriate than direct sale to abattoirs (Weeks, McNally, & Warriss, 2002). For these reasons, one of the major international restaurant companies no longer allows its European beef burger suppliers to source meat from cattle sold through auction markets. An alternative approach might be to address the welfare concerns by identifying the key issues at the markets and then manage those issues in the most appropriate way.

In a study of 18 cattle markets in the UK, the key welfare issues were found to be slips and falls in fat cattle during unloading, grading, putting-up to and through the sale-ring, impacts during grading and at specific places when passing to and through the ring,

Table 5
Prevalence of handling problems in fat cattle in UK markets during 2006/2007

	Prevalence % (range for the markets)		
	Refusal and balking	Slips and falls	Impacts
Unloading	0.6 (0–4.8)	5.8 (0–20)	0.6 (0–3.6)
Grading	12.9 (0–32)	23.0 (0–84.6)	34.4 (1.0–64.4)
Putting-up to the ring	17.6 (0–68.3)	15.7 (0–43.1)	21.7 (0–35.9)
Passing through the ring	5.1 (0–17.6)	21.5 (4–65.9)	6.0 (0–33.3)
Passing from the ring	3.1 (0–10)	9.6 (0–33)	14.2 (0–76)
Loading	12.2 (0–27.8)	3.0 (0–15.0)	1.1 (0–3.6)

slips and falls during loading in calves, and refusal to load amongst cattle after the sale (Table 5; Gregory, Benson, et al., in press). In a comparable study of 24 UK sheep markets, the prevalence of these and other welfare-related problems was very low.

Slips and falls occurred when there was manure plus rain or urine on the concrete floor, especially at bends where running cattle made a turn. When the skid resistance value for wet concrete is greater than 55 British pendulum number (BPN), the prevalence of falls is less than 2% and the prevalence of slips does not exceed 14%. Below 55 BPN, the risks rise. Some cattle markets have installed resin plus grit screeds over concrete in high-risk areas, and they seem to be very effective. Similarly, resin screeds can be applied to metal weighbridges where these pose a problem.

Many UK cattle markets have two-way gates at the entrance of the holding pens. These have a centre gatepost supporting two gates that open at opposing ends allowing cattle to enter and leave the pen in both directions along the corridor. The disadvantage with these pens is that the entrance can be narrow, and this presents bruising points at the centre and corner posts. The prevalence of impacts from this and other causes when putting cattle up to the sale ring was 12.5% (Gregory, Benson, et al., in press). Impacts were also frequent during grading, and this is a common feature with any work on cattle in crushes, races or other confined spaces. One way of reducing movement and the likelihood of severe impacts is to temporarily section the raceway into a series of individual pens using sliding gates. This stops cattle shunting up and down the raceway, and it stops horned cattle burrowing under an animal in front. Not all markets had raceways with a sliding gate system.

At some markets, loading is difficult because the loading pen is too wide. Milling and circling occurs when the pens are more than 4 m wide. The height of the loading platform above the vehicle also influences ease of loading. Where it is high, cattle have a clear view downwards into the vehicle and they sometimes refuse to load. This was a serious problem at one market, where the height difference was 93 cm (Gregory, Benson, et al., in press). Applying straw to the loading tailboard was said to make loading easier, but this was rarely used. Placing straw on dry concrete can make the floor slippery and so it is not recommended for unloading.

In the UK study, 11% of calves fell during loading. This usually happened when they failed to raise their feet adequately whilst moving onto the tailboard. Instead, the leading fore leg folded at the knee and was followed by the second fore leg. If the person doing the loading pushed the kneeling calf from behind, it was prone to going over on its side. Less commonly a calf fell off the side of the tailboard, and became lodged between the tailboard and loading pen side gate.

During grading the cattle are usually held in a race or crush, the eartag number is checked against that of the passport, a salelot number is applied to the back and a sale category is registered. Impacts during grading were mainly with gates and other animals, and refusal to enter the crushes was the single most important reason for hindered movement. Slippery floors and lost footing were the main contributors to slips and falls.

Other countries have different problems at cattle markets. In Ontario and Quebec the main issue recently has been submission of sick dairy cows, especially when the milk quota has been tightened (Cochrane, personal communication). This has been made worse by a cost-cutting reduction in veterinary livestock inspectors at markets.

About 20 years ago it was thought that electronic marketing would displace traditional live auction markets. This has not happened, but there are some feedlot regions where first-price sealed-bid auctions have become common (Crespi & Sexton, 2004). Feedlot operators provide weekly show lists of lots of cattle available for sale, and abattoir representatives may visit the feedlot to inspect these cattle. Bids are submitted as sealed bids by phone or fax, and competing abattoirs do not know who has bid on the various lots and at what price. The feedlot accepts or refuses a bid, and usually the first bidder is given an opportunity to revise his bid in the event that someone offers a higher price. This system works well where there are many feedlots and processors using the system simultaneously.

About 30% of cattle in the USA are now sold through a grid pricing system. This method has been controversial because it is thought to aid price control by a declining number of abattoirs, and it relies on meat and carcass quality assessments made on the slaughterline which are thought to be too subjective (Schroeder, Mintert, Ward, & Wheeler, 2003; Whitley, 2002). Confidence in the quality-related criteria needs to be improved.

5. Slaughter without stunning

When cattle are slaughtered without stunning some animals take a long time to lose brain function and die. This has been shown experimentally using somatosensory evoked responses in the brain and from the delay before the animal collapses (Blackmore, 1984; Daly, Kallweit, & Ellendorf, 1988). It is thought that the delay is due to a combination of false aneurysms in the severed carotid arteries plus sustained flow of blood to the brain through a plexus connecting the vertebral arteries with the carotid rete (Baldwin, 1960). False aneurysms are also known as ballooning. The severed artery retracts within its surrounding connective tissue sheath, the connective tissue becomes impregnated and swollen with blood and this can occlude flow from the cut artery. About 8% of cattle slaughtered by shechita and halal, without stunning, develop false aneurysms in both carotid arteries (Gregory, von Wenzlawowicz, et al., 2008). When this happens there is a risk that blood flow from the severed caudal ends of the arteries stops and the animal takes longer than usual to lose consciousness and die. The next piece of work that needs to be done is to find ways of avoiding false aneurysm formation.

Some authorities claim that aspiration of blood into the upper respiratory tract and lungs causes suffering during slaughter without stunning (Von Wenzlawowicz & von Holleben, 2007; Webster, 1994). Others take the view that there will be no suffering because afferent signals activated by lung irritation are conveyed by neurones within the vagus nerves (King, 1999), and these are severed during slaughter without stunning. More recently, it has been shown in a range of laboratory animal species that there is a collateral spinal afferent pathway between the lower respiratory tract and the brain, which passes through the cervicothoracic (syn. stellate) ganglia and the dorsal root ganglia at T_{2-4} (Qin, Foreman, & Farber, 2007). This pathway could relay signals that are interpreted in humans as tickling, tearing or burning sensations provoked by chemical and physical stimuli in the alveoli of the lungs (Hummel, Sengupta, Meller, & Gerhart, 1997). About 19% of 123 cattle slaughtered by shechita in the upright position were found to have blood in the trachea (covering >10% of the inner surface area), and 36%

Table 6
Effect of three slaughter methods on weight loss (±SE) in lamb meat

	Electrical stunning 110 V, 50 Hz, 5 s, head only	CO_2 stunning 90%, 90 s	No stunning
Number of lambs	10	10	10
Drip loss (%)	1.53 ± 0.18[a]	1.84 ± 0.30[a]	0.52 ± 0.03[b]
Cooking loss (%)	15.09 ± 0.92[a]	11.70 ± 1.18[b]	6.04 ± 0.36[c]

Means in a row with a different superscript letter were significantly different at least at $p = 0.05$.

had blood in the bronchi (Gregory, in press). These prevalences were similar to those in 103 cattle shot by captive bolt and gash stuck whilst in the same upright position (21% and 31%). Ten percent of the shechita cattle had bright red blood foam in the trachea, whereas none of the secular cattle showed this effect. Taken together this information suggests that the welfare concerns about blood aspiration during shechita are warranted.

In the UK there are about 2 million Muslims, and yet it is said that there are 6 million consumers of halal meat. This claim has not been authenticated, but the reasoning behind it has a logical basis. It is claimed that there is a perception that halal meat carries less risk of transmitting BSE. This is consistent with the fact that captive bolt stunning introduces a risk of brain emboli embedding in the edible carcass. However, that view is not consistent with recent reports from Turkey, where two separate studies showed that 9% and 10% of retail meat products contained central nervous system (CNS) tissue, as determined with the glial fibrillary acidic protein ELISA test (Nazli, Colak, Hampikyan, & Bingol, 2006). Since the main slaughter methods in Turkey are halal and shechita, it is highly unlikely that the CNS material arose from brain emboli developing after shooting by captive bolt. Instead it is likely that the CNS tissue arose from the spinal cord during carcass splitting (Lim, Erwanto, & Lee, 2007). Carcass splitting is probably the single biggest risk factor in transferring the BSE prion to edible meat in an infected carcass, and it can occur independently of the stunning or slaughter method.

Most meat scientists would accept that meat quality in stunned cattle and sheep is comparable to that from animals slaughtered without stunning. There has, however, been a recent exception. When 25 kg lambs were slaughtered without stunning, their meat developed less drip before cooking, and had less cooking loss, compared with meat from electrically or CO_2 stunned lambs (Linares, Bórnez, & Vergara, 2007; Table 6). Whether this was sufficient to influence meat succulence was not tested.

6. Electrical stunning

There have been doubts amongst some onlookers about the effectiveness of electrical stunning in large cattle, especially when it has been accompanied by a current that induced a cardiac arrest. This was examined recently in 67 cattle stunned with 2.3 A applied between the neck and nose for 2.2 s, followed by a current delivered to a brisket electrode to stop the heart. The animals were stuck at 90 s after the end of electrical stunning. The depth of the stun was assessed from brainstem reflexes and spontaneous behaviours as indicated in the footnote to Table 7. Just under half the animals showed no positive features following electrical stunning, and 8% showed three positive features at both 20 and 90 s after electrical stunning.

Positive brain stem reflexes and behaviour patterns might have been due to residual brainstem activity and would not in isolation signify consciousness. However, three positive features in the same animal creates the impression that the animal is not deeply stunned and that it needs to be shot. Twelve out of the 67 animals (18%) were shot with a captive bolt gun after they had been electrically stunned because the slaughterman was concerned about the effectiveness of the stun. Shooting was done by the operator performing the shackling, without any prompting from an observer. In animals where behaviour assessment was possible, each shot animal had on average two positive features just before it was shot. The prevalence of cases that are shot needs to be reduced in order to improve confidence in this stunning method.

Another concern has been the physical activity shown by birds subjected to DC electrical stunning, compared to AC electrical stunning. Fifty Hz AC currents are sometimes used for some secular markets, whereas higher frequency DCs are often used for halal markets because they do not induce a cardiac arrest at stunning. The two were compared at a processing plant using the settings preferred by the plant manager (106 mA per bird 50 Hz AC, and 51 mA per bird 100 Hz DC). The quality of the stun was adequate in both cases, but the DC stunned birds were more active (Table 8).

It is suspected that high voltage stunning might contribute to producing PSE meat in pigs, but the evidence for this has always been sketchy. Few studies have used sufficient number of pigs or applied the stunning currents in ways that are usually adopted

Table 8
Prevalence of physical activity and responses following AC or DC electrical stunning and slaughter in broilers

	AC	DC
Birds showing breathing movement (%)	0[b]	20[a]
Birds showing physical activity (%)	0[b]	18[a]
Birds head flicking (%)	2[b]	8[a]
Birds showing beak gaping (%)	0[b]	8[a]
Birds with a response to comb pinch or touching the head (%)	0[b]	3[a]
Birds with corneal reflex (%)	1[b]	3[a]

Means in a row without a common superscript letter were significantly different at $p < 0.05$. There were, on average, 197 broilers in each prevalence estimate (Gregory and Stanikova, 2008, unpublished).

Table 9
Prevalence of PSE carcasses (%) in abattoirs using different stunning voltages

Stunning voltage	Number of pigs	Normal	Mild PSE	Severe PSE
220–240	67,638	87	2	11
250–280	19,556	71	5	24
430	2795	63	6	31

Table 7
Proportion of animals with positive responses or behaviours after electrical stunning with a cardiac arrest

Time after electrical stunning seconds	Percent of animals with positive features [a]		
	No positive features	One of more positive features	Three or more positive features
20	40	60	8
90	45	55	8

[a] Each animal was assessed for six behavioural features at 20 s and at 95 s after the end of electrical stunning. The features were presence or absence of rhythmic breathing, corneal reflex, palpebral reflex, response to pinching the tongue, spontaneous blinking, and physical response to stimulation of a nostril.

commercially. In a recent study involving over 91,000 pigs at seven abattoirs in Korea, the prevalence of PSE meat was higher where high voltages (>300 V) were used (Table 9). Rapid chilling helped reduce the PSE (Park et al., 2007).

7. Gas stunning

Many pig abattoirs that have adopted CO_2 stunning, use 90% CO_2. The minimum concentration that is usually recommended is 80 %, and this was based on work originally conducted in Germany. More recent work from Germany has indicated that 90% causes less physical stress than 80%, as it results in a less pronounced metabolic acidosis, but 90% can cause behavioural aversion (Nowak, Mueffling, & Hartung, 2007; Table 10; Velarde et al., 2007).

Five gas stunning systems have been developed for broilers, and two of them are gaining popularity (Gregory, 2005). They are the UK method which uses 60% argon plus 30% CO_2, and the Dutch method which uses 40% CO_2 plus 30% O_2 followed by 80% CO_2 plus 5% O_2. Recent work confirmed practical experience that the Dutch method results in less convulsions, fewer fractured wings and less breast meat haemorrhages (McKeegan et al., 2007). It also showed that there was slightly tougher meat during the initial stages post-mortem with the Dutch method, but this effect disappeared with aging.

8. Captive bolt stunning

In the US the prevalence of repeat shooting with the captive bolt has declined in recent years (Table 1). Some slaughtermen in the UK have, however, been concerned about variation in the noise made by their captive bolt guns. Soft sounding shots are thought to be less effective. A recent study confirmed this concern (Gregory, Lee, & Widdicombe, 2007). Shots from 4.5 gr cartridges fired with a Cash 8000 Bulldozer that were less than 111 dB were associated with a shallow depth of concussion.

There are three sources of noise when an animal is shot with a captive bolt gun. They are the discharge of the cartridge, the noise of the bolt when it strikes the skull, and the noise produced by breaking the bone. The detonation of the cartridge is the loudest of the three, but it is not known whether it is the main source of variation in shot loudness. Intuitively one would expect either dampness within some cartridges or variation in gunpowder fill in the cartridges to be likely sources of loudness variation. When cartridge fill was estimated from the difference between full and empty cartridge weight (after removing spent residue by washing), it was found to be related to discharge noise (Table 11). In other words, the noise emitted by shots from the same grain of cartridge (as supplied by the manufacturer), can be influenced by variation in gunpowder fill in those cartridges. This effect was independent of any variation in noise associated with striking a target, as the gun was fired in air.

Noise variation in shots could however be partly due to differences in the nature of the target that is struck. For example, when a Cash Special loaded with 2.5 gr cartridges was fired into medium density fibre (MDF) board (made from wood waste and resin glue) of different thicknesses but the same surface hardness (36 Shore D durometer units), the noise of the shot increased with increasing thickness of the board (Table 12). Whether this was due to differences in the way noise was emitted from the gun, the impact noise or the noise from breaking the target was not determined. The implication is that skull differences might contribute to differences in noise produced by a shot.

8.1. Gun firing rate

The captive bolt is a very effective stunning device when used properly, but its main weakness is that cartridge-fired guns do not cope with high line speeds. It is occasionally used in high throughput lamb plants that choose to stop using electrical stunning and change to a captive bolt during the season when blood splash is worst. At high shooting rates guns get hot and the metal surface becomes too hot to hold for more than 5 s when it reaches 50 °C. They need to be rested to allow them to cool, and so, more than one gun is needed. The only alternative is to wear a thick leather glove, but this may not be compatible with local hygiene requirements.

The heat generated by a captive bolt gun comes from three sources. They are the heat produced by:

Table 10
Effect of 80% or 90% CO_2 stunning on subsequent plasma lactate and meat quality (±SE) in pigs

	80% CO_2	90% CO_2
Number of pigs	69	80
Plasma lactate mmol/l	8.8 ± 0.8[a]	6.4 ± 0.5[b]
pH_{45} *semimembranosus*	6.06 ± 0.02[b]	6.38 ± 0.03[a]
pH_{45} *longissimus*	6.13 ± 0.01[b]	6.42 ± 0.03[a]

Means in a row with a different superscript letter were significantly different at least at $p = 0.05$.

Table 11
Difference in peak noise emitted from 2.5 g cartridges in a Cash Special captive bolt gun fired in air, according to cartridge fill with gunpowder

Range in cartridge fill mg	Number of cartridges	Noise dB ± SE
0.2017 to 0.2237	64	101.58 ± 0.19
0.2238 to 0.2255	29	102.34 ± 0.35

The noise difference was significantly different at $p < 0.05$. (Gregory and Lee, 2008, unpublished).

Table 12
Effect of target thickness on peak noise emitted from captive bolt gun shots

	Target thickness (mm)			
	0[a]	3	6	9
Number of shots	93	20	20	20
Mean (dB)	101.8[a]	102.5[ab]	105.3[b]	106.1[b]
±SE	0.2	0.2	0.3	0.3

[a] Gun fired in air. Means in a row without a common superscript letter were significantly different at $p < 0.001$ (Gregory and Lee, 2008, unpublished).

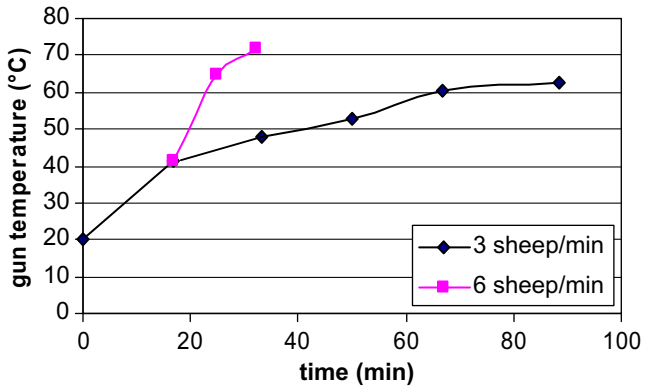

Fig. 1. Gun temperature rise when shooting at high firing rates.

- explosion of the gunpowder;
- friction of the bolt as it enters the target;
- transfer of energy during compression and relaxation of the recuperating sleeves in the gun.

The bolt is likely to be the hottest part of the gun, especially at the breach end. When temperature measurements were made in a pistol type gun using an infrared thermometer, the points on the outer surface that were hottest were just above the position of the trigger and above the point where the bolt rests when it is fully retracted and in the ready-to-fire position. The latter position corresponds to the thinnest part of the gun chamber and is in contact with the resting bolt. Heat transfer occurs mainly between shots.

The overall rate of rise in temperature at this position when shooting ewes at three shots per min with a Cash Special plus 2.5 gr cartridges is shown in Fig. 1. This is compared with six shots per min using the same gun when it is already warm. This figure emphasises the impracticality of using a captive bolt gun at high kill rates.

The rate of temperature rise in a gun is also an indirect measure of the energy retained by the gun instead of being transferred to the animal as a concussive blow. The rate of temperature rise could depend on the type of animal being shot. The principles behind this become clear when considering Fig. 2. In this trial the shooting substrate was MDF board plus a single layer of carpet top-cover, made of non-woven synthetic fibre which was 5.6 mm thick when compressed by a 2.6 g/mm^2 load. The relationship between temperature rise in the gun and thickness of the MDF board was bimodal (Fig. 2). Increasing heat transfer to the gun in the ascending limb of the relationship would have been due to the greater friction involved in puncturing the board. Whereas the decreasing heat transfer to the gun in the descending limb would have been due to greater energy transfer to the target and less energy imparted to the recuperating sleeves in the gun. This finding has implications for estimating energy transfer as a concussive blow. In the past, energy transfer has been estimated from the difference in deceleration of the bolt as it enters the brain relative to the rate of deceleration when the same gun-cartridge combination is fired in air (Gregory, 2007). With that approach it would be difficult to estimate and correct for differences in heat transfer to the gun because of variation in skull thickness, but there are few alternatives.

9. Water buffalo

In the European Union slaughtermen are not allowed to shoot cattle in the poll position when using captive bolt guns. They must shoot bovines, which include water buffalo, in the frontal position. This is because there is a less profound depth of concussion with poll shooting (Daly, 1986). Practical experience indicates that shooting water buffalo with captive bolt guns in the frontal position is not always effective, and that physical collapse is more likely when using a poll shot. This is thought to be due to their massive frontal bones, which can be as thick as 8 cm.

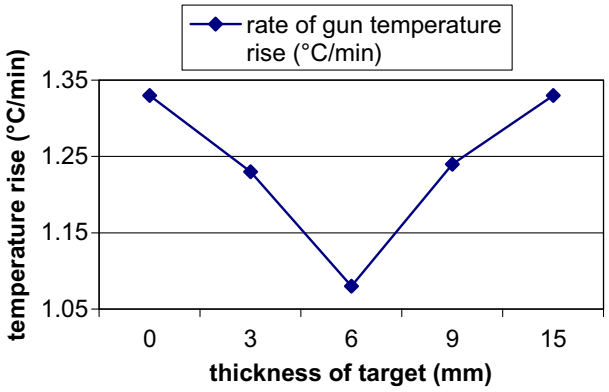

Fig. 2. Relationship between thickness of the target and rate of temperature rise in a captive bolt gun fired repeatedly at three shots per minute. Surface hardness of the different thicknesses of target was the same (36 Shore D durometer units). In all cases the target was punctured by the bolt. (Gregory and Lee, 2008, unpublished).

In a recent study on 30 water buffalo shot at abattoirs in the poll position, in all but three animals the bolt entered the brain. In two exceptions the animals were shot through the spinal cord. There were two other animals in which the depth of concussion was considered to be shallow, in one of which the bolt had not entered the brain and it was re-shot by the slaughterman, and in the other there were three signs of brainstem activity. The conclusion was that poll shooting can be effective when using an appropriate gun and the appropriate shooting direction in the head, but it was prone to operator error and misdirecting the bolt at the spinal cord instead of the brain.

It is possible, however, that the spinal cord-shot buffalo were concussed. In humans, recognising which regions of the brain are injured can be helpful in establishing the neurological functions that have been affected, and in assessing prognosis. For example, injury to the cerebellum alone has been associated with loss of balance and collapse, or inability to stand upright (Arné, 1975). It can also be associated with eye movement, which is slower than normal nystagmus. Medullary dysfunction has usually been associated with acute vertigo and ataxia (Currier, 1969). Breathing is absent if there has been involvement of the reticular formation within the medulla. Injury to the pons has been associated with coma, and disturbances in breathing rhythm would be common (Omae, Ueda, Ogata, & Yamaguchi, 1989). More extensive injuries involving the rostral portion of the pons, cerebellar peduncle, midbrain, and the forebrain regions bordering the midbrain, have a catastrophic effect on consciousness (Saper & Plum, 1985). Taken together this indicates that shots directed at the brainstem should provide a more certain induction of unconsciousness.

However, shooting the brain stem is not consistent with obtaining an undamaged brainstem sample for BSE testing in over 30 month old animals. The trials in water buffalo indicated that aiming the gun in the poll position of over thirty month old water buffalo so that the bolt missed the brainstem and allowed sampling of an intact brainstem for BSE testing, did not compromise the quality of the stun.

If poll shooting is to be allowed, it must be accompanied by appropriate training where the slaughtermen are aware of the importance of shooting direction, and the need to stick promptly to minimise the opportunity for recovery. In addition, high velocity captive bolt guns must be used (e.g. •25 trigger firing captive bolt guns fitted with 5.0 gr cartridges (Magnum 9000, Accles & Shelvoke Ltd, UK) or 3.5 gr cartridges (Matador Super Securit 3000, Termet Solefi, France)). The recommendation from the research is that poll shooting should be acceptable in water buffalo provided the correct gun-cartridge combination is used, and provided the operators are given appropriate instructions.

10. Frangible shot

Farmers and home-kill operators do not usually own captive bolt guns. Instead they often use a shotgun or rifle for large stock, and sticking without stunning for sheep or goats. It would be good to have a safer alternative to shotguns and free bullets for cattle, and to use equipment that does not create brain tissue or lymph node splatter. Frangible ammunition is used as a safe alternative to steel or lead shot by some police forces and militia. It was originally developed to reduce collateral damage during hostage-res-

cue operations. Frangible rounds come in a variety of configurations, all of which perform in the same basic manner. Some contain very small metal pellets held together by a binding agent, others are metal powder heated until the particles adhere together to form a slug or bullet. Upon impact, the pellets, with a low mass to surface area ratio, stop very quickly and the slug or bullet disintegrates into dust. The risk of ricochet is greatly reduced, if not eliminated. Frangible cartridges have apparently been fired from 12-bore shotguns at near point-blank ranges to shoot the lock mechanism out of doors without harming the occupants of the room or the firer.

Most published accounts on the use of frangible ammunition in animals have been on pigs. Kaplan, Klose, Fossum, and Di Maio (1998) used frangible ammunition made from fine iron particles held together by an organic binder. They also tested newer versions of frangible bullets that were constructed from non-ferrous metals such as copper. They fired 36 gr •223 in. calibre bullets into pigs heads from a range of 1 m. The bullets fragmented and particles tended to remain in the target tissues and none displayed sharp prominences or acutely angled irregularities that might have been dangerous had they exited.

Recent trials using micronised bismuth–calcium carbonate loads suggest that reducing the power of the shotgun cartridge reduced the residual ricochet risk to operators. Most of the ricochet risk was from pieces of wadding that might deflect off a hard surface, particularly if the projectile over-penetrated. The bismuth round was preferable to the stainless steel cartridge, because the natural clumping of the bismuth particles under compression avoided the need for a plastic container, which potentially could ricochet but was necessary to hold the spherical steel shot together until impact. Low-power cartridges should reduce tissue splatter, but the reduction was found to be inconsistent, in part because unpredictable gas blast effects added to the impact of the projectile, and were an unavoidable consequence of taking shots at near point-blank range (Karger, Nüsse, Schroeder, Wüstenbecker, & Brinkmann, 1996). When a shot does not pass completely through a head, the pressure inside the cranium can only be relieved through the mouth or the entry wound. This contributes brain tissue splatter, which is comparable to that from a high-velocity rifle bullet. Nevertheless, splatter with many of the shots was negligible. It is difficult to predict with certainty the likelihood and amount of splatter resulting from frangible shots, but most tissue was expelled away from the firer. Using the lowest powered cartridge should minimise the risks but does not totally eliminate them and so operators should be encouraged to use suitable protective clothing and adopt firing positions that avoid any part of the body being directly above the animal. In this respect, using a firearm with a 28 in. barrel enables the firer to avoid close contact with the animal. More experience is needed before claims can be made about the welfare aspects of frangible shot, but initial indications are that it immediately reduces much of the brain to a pulp.

11. Fish

About one-third of world fish consumption now comes from fish farms. New fish species are being trialled by the aquaculture industry, and one that is raising hopes in northern Europe is cod (*Gadus morhua*). Cod have been successfully ranched off the coast of Newfoundland but now the focus is in breeding and then rearing market-size fish from larvae. In terms of meat quality one of the weaknesses with cod is its tendency to gape and become soft. Trials on killing methods used in ranched cod have shown that transporting fish to the shore and stunning them with CO_2 resulted in an acidosis at slaughter and meat with more gaping and softer texture compared with fish killed by concussion at the sea cage (Kristoffersen, Tobiassen, Steinsund, & Olsen, 2006). The feasibility of slaughtering at the cages depends on processing the fish before rigor sets in and this depends in part on the time it takes to transfer them to the processing facility.

CO_2 stunning causes considerable stress in salmon and trout, and it is falling from favour. Increased physical activity immediately before the fish are stunned can result in external damage and downgrading, earlier onset of rigor and reduced yield during filleting, softer texture on resolution of rigor, loss of colour, gaping, increased susceptibility to oxidative rancidity and greater water loss. Using deoxygenated water is less stressful for trout, in terms of epaxial muscle ATP depletion at the time of death, and emersion is also less stressful (Wills, Zampacavallo, Poli, Proctor, & Henehan, 2006). In salmon, live chilling-CO_2 stunning systems are replacing the conventional CO_2 stunning system. The fish are exposed to chilled seawater (down to 1 °C) before stunning. This cools the muscle and makes the fish less active and reactive to CO_2 saturated water. However, one study has shown that live chilled salmon (4–5 °C) develop a more prompt rigor than fish killed from 14 °C water (Roth, Slinde, & Robb, 2006). A separate study showed a longer delay in time to rigor with the live chilling-CO_2 stunning system (Erikson, Hultmann, & Steen, 2006). The reason for the difference between these studies needs clarifying, and it probably lies in the handling stress that can occur before applying the stunning method. Another approach to controlling physical activity with CO_2 stunning has been to sedate the fish with either iso-eugenol or clove oil beforehand (Bosworth et al., 2007; Ribas et al., 2007).

Electrical stunning has been tried recently in tuna (*Thunnus thynnus*). High frequency DCs (1 kHz) are prone to producing blood spots in the meat and broken spinal cords, but this can be reduced by using intermittent pulses of the same DC (Soto et al., 2006). Very low frequencies (intermittent 20 Hz DC or 20 Hz AC) resulted in least damage, and it would be interesting to see reports on the effectiveness of the stun.

Recommended electrical stunning currents, based on the induction of an epileptiform EEG, have been reported for carp (*Cyprinus carpio*) and catfish (*Clarias gariepinus*) (Lambooij, Kloosterboer, Gerritzen, & van de Vis, 2006; Lambooij, Pilarczuk, Bialowas, van den Boogaart, & van den Vis, 2007). Killing grass carp (*Ctenopharyngodon idella*) in an ice slurry has resulted in lower counts of mesophiles and psychrotrophes in skin plus muscle samples for up to 16 days following slaughter compared to electrically stunned chilled fish (Scherer et al., 2006).

12. Welfare and hygiene issues at wet markets

In tropical countries, freshness is an over-riding prerequisite for meat and other foods. Because of this, live animals are often held in cages at stores or market stalls, and slaughter and butchering are performed in front of customers upon request. For some customers, it is important to see the animal live before being sold. Specifically, they may want to check the health status and quality and select an animal accordingly. This is generally not an option in supermarkets, except in lobster or some fish. The welfare concerns with the wet markets include the following. Small animals are often sold on a liveweight basis, and birds are sometimes force-fed to increase weight and sale price. Animals not sold on a given day have to be carried over to the next. Unsold animals can be the ones that are in poorest condition or least healthy, and the standard of care can be rudimentary. In busy markets, some animals may be stressed through repeated handling before someone decides to buy them.

In addition, wet markets do not have a good reputation for standards of cleanliness. Live animals come into direct contact with sales

clerks, butchers and customers, and there is ample opportunity for indirect transfer of dirt from an animal to edible meat and offal. Insects such as flies have relatively easy access to foods in the markets. In China the food safety concerns about wet markets have been increasing, and they came to a climax with the pork and chicken-related human disease outbreaks that arose on mainland Hong Kong. This created greater interest in developing centralised slaughter and meat processing facilities, but these have not always been cost-competitive with household slaughter, nor have they sat comfortably with sectors such as the Hui Minority who make a living from supplying wet meat (Brown, Longworth, & Waldron, 2002).

13. 'Public morality' as a non-tariff trade barrier

The WTO does not recognise animal welfare as a justified non-tariff trade barrier between nations, except when it is part of an explicit trade agreement between those nations. The Office International des Épizooties (OIE) is trying to establish international agreements on acceptable animal welfare standards, and, provided the WTO recognises those standards, lack of compliance could become legitimate grounds for resisting importation of specific items. There has been no test case yet which establishes whether or not this is the way the rules will be interpreted, but it could be the way things move forward. Another development that is on the horizon is denial of trade access on the grounds of public morality. This is being considered within the EU as legitimate grounds, under the Treaty of Amsterdam, for denying the importation of seal pups skins from Canada. Here again, it is too early to say whether or not this will be upheld, but if it is it could open up other opportunities for introducing non-tariff trade barriers against some meats and meat products.

14. Conclusions

Based on the information reviewed in this paper it is suggested that the following should be considered as future research and development aims. Firstly, we need to know more about the ways in which stress influences gut microflora and the excretion of potential pathogens. The knowledge would benefit meat hygiene, as well as animal and human health. The place of livestock markets in society needs to be considered in an open-minded manner. Regional differences need to be taken into account as well as the role that livestock play in different communities. The need for traditional livestock markets is probably greatest in Africa. Livestock markets play a key part in the local and household economy, and in recruiting livestock from villages for transfer to metropolitan regions for meat consumption. Whereas, in other parts of the world there is the growing view that that fatstock markets are not essential to the meat and livestock industries. Perhaps thought needs to go into reducing the risk of injuries during routine handling procedures at markets instead of boycotting meat procured from livestock purchased at markets. Improving welfare and hygiene standards in wet markets may also be a way ahead, instead of attempting to replace them with supermarkets. There is a view within Europe that the additional handling imposed by checking cattle passports needs to be reconsidered, and remote animal identification methods may help solve the animal welfare problems connected with reading ear tag numbers.

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